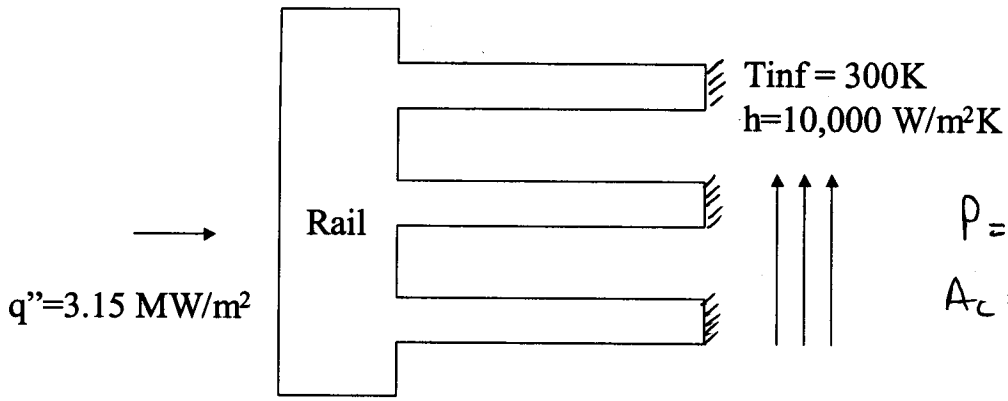
Steady State Analysis of EM Railgun with Fins

Assumption – Heat is deposited into the rail by a constant surface heat flux and the inside face of the rail. The rail and the fins are pure copper (k=401 W/mK).

Rail Length = 10 m



$P = 20.02\ m$

$A_c = 0.1\ m^2$

$k = 401\ W/mK$

Rail: thickness 20 mm
height 120mm

Fins: thickness 10 mm
length 60 mm
Width 10 m

1) Determine the effectiveness and the efficiency of the fins. Make at least two suggestions for improving the fin design and efficiency

2) Calculate the temperature at the heated face of the rail.

   a) straight line heat flux

3) ~~b) planar isotherm~~ no fins

1) $q_f = M \tanh mL = \sqrt{hPKA_c} \tanh\left(\sqrt{\frac{hP}{KA_c}}\, L\right)$

$q_b = h A_c \theta_b$

$\varepsilon_f = \sqrt{\frac{PK}{hA_c}} \tanh\left(\sqrt{\frac{hP}{KA_c}}\, L\right)$

$\varepsilon_f = 2.83 \tanh(4.24)$

$\varepsilon_f = 2.83$

$$\eta_f = \frac{q_f}{q_{max}}$$

$$q_{max} = h A_f \theta_b$$

$$A_f = (W \times L)2 + 2(t \times L)$$

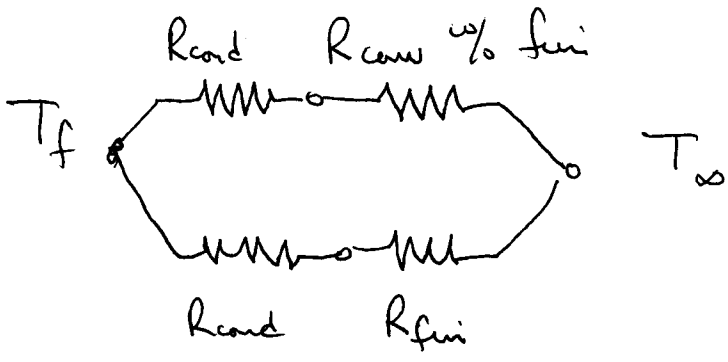
$$A_f = 1.2012 \ m^2$$

$$\eta_f = \frac{\sqrt{hPkA_c}}{hA_f} \frac{\tanh(mL)}{\theta_b} \cong 1$$

$$\eta_f = 23.6\%$$

2) Calculate temperature at heated face.

Straight line heat flux



$$A_f = 3 \times A_c$$

$$A_f = 0.3 \ m^2$$

$$A_{w/o f} = 0.9 \ m^2$$

$$R''_{cond} = \frac{L}{k} = 4.987 \times 10^{-5} \ \frac{m^2 K}{W}$$

w/o fin

$$R_{cond} = \frac{L}{k A_{wof}} = 5.5417 \times 10^{-5} \ \frac{K}{W}$$

w/ fin

$$R_{cond} = \frac{1}{k A_f} = 1.662 \times 10^{-4} \ \frac{K}{W}$$

$$R_{conv} = \frac{1}{h A_{w/o\,f}} = 1.111 \times 10^{-4} \ K/W$$

$$R_{fin} = \frac{\Delta T}{q} = \frac{\theta_b}{3\sqrt{h P k A_c}\ \tanh(mL)\ \theta_b}$$

$$R_{fin} = 1.176 \times 10^{-4} \ K/W$$

$$R_{tot} = \left[\frac{1}{R_{cond\ w/o\,fin} + R_{conv}} + \frac{1}{R_{cond\ w/o\,f} + R_{fin}} \right]^{-1}$$

$$R_{tot} = \frac{1}{1.6657 \times 10^{-4}} + \frac{1}{2.838 \times 10^{-4}}$$

$$R_{tot} = 1.0496 \times 10^{-4} \ \frac{K}{W} \qquad q = 3.78 \times 10^{6} \ W$$

$$\Delta T = 396.7$$

$$T_f = 696.7 \ K$$

3) Calculate the temperature of the heated face w/o fins

$$R_{tot} = \frac{L}{kA} + \frac{1}{hA}$$

$$R_{tot} = \frac{0.02\ m}{401\ W/mK \cdot 1.2\ m^2} + \frac{1}{10{,}000\ W/m^2K \cdot 1.2\ m^2}$$

$$R_{tot} = 1.249 \times 10^{-4} \ \frac{K}{W}$$

$$\Delta T = 472.1 \ K$$

$$T_{face} = 772.1 \ K$$